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Resources

DWR-1224
Revised

BEFORE THE

CALIFORNIA STATE WATER RESOURCES CONTROL BOARD

HEARING IN THE MATTER OF CALIFORNIA DEPARTMENT OF WATER RESOURCES AND UNITED STATES BUREAU OF RECLAMATION REQUEST FOR A CHANGE IN POINT OF DIVERSION FOR CALIFORNIA WATER FIX	**TESTIMONY OF PAUL HUTTON**

I, Paul Hutton, do hereby declare:

I.   INTRODUCTION

My name is Paul Hutton. I am a Registered Professional Civil Engineer in the State of California (License #40795). I am employed as an engineering consultant with Tetra Tech, Inc. I also serve as the executive director for the California Water and Environmental Modeling Forum. My educational background includes a Bachelor of Science in Civil Engineering with Highest Honors from the University of Illinois (1983), Champaign-Urbana, a Master of Science in Civil and Environmental Engineering, also from the University of Illinois (1984), and a Doctor of Philosophy in Civil and Environmental Engineering (1994)

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from the University of California, Davis. I have 33 years of professional engineering

experience, including a 27-year career with the California Department of Water Resources

and the Metropolitan Water District of Southern California. A significant focus of my career

has been on modeling and operations-regulatory analysis related to water quantity, water

quality, and water supply reliability in California's Sacramento-San Joaquin Delta and

Central Valley. I have authored 13 scientific papers that have been published in peer-

reviewed journals; one was recognized by the American Society of Civil Engineers with an

outstanding journal paper award and several are offered in this testimony as exhibits. A

true and correct copy of my statement of qualifications is marked as DWR-1206.

> My testimony is in response to CSPA (CSPA-202, p. 2) testimony that:
> In considering conditions to place on the permits for the SWP and CVP in
> this proceeding, the Board can and must evaluate conditions for all
> aspects of SWP and CVP operation, not just those immediately related to
> the new points of diversion.

I am also responding to NRDC, PCFFA, Contra Costa County and Contra Costa Water

Agency, and City of Antioch who specifically raised the issue of the diversion of fresh water

and the alteration of natural flow patterns in recent years and decades. (NRDC-58, errata,

p. 4, PCFFA-145, CCC-SC-3, Antioch-500, errata.) I am also responding to the Protestant's

testimony related to restoring "natural" flow patterns and support for the wholesale adoption

of all of the analysis and conclusions in the Water Board's 2010 Flow Policy Report and the

Water Board's Phase II Technical Basis Report. (CSPA-202, errata, pp. 7-11; April 11,

2018, Transcript, Vol. 28, p. 122; April 24, 2018, Transcript, Vol. 33, pp. 110-115; PCFFA-

161, p. 8:7-9.) Several parties' experts recommended that the Water Board's 2010 Flow

Criteria Report and the Water Board's Phase II Technical Basis Report should be accepted

without modification, suggesting that there was no new relevant information that should

also be considered. This suggestion is not accurate as there has been a large body of

highly relevant scientific investigation over the last eight years. My testimony is intended to

identify new information, including seven peer-reviewed publications I personally authored

or co-authored, suggesting that the 2010 Flow Policy Report and the Phase II Technical

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Basis Report should not be implemented without further consideration of the current best available science.

The opinions offered in this testimony are based on my experience and work I conducted in collaboration with colleagues and documented in the following peer-reviewed journals, all of which were published subsequent to the release of the State Water Board's 2010 Flow Criteria Report:

- Hutton, P.H., J.S. Rath, and S.B. Roy (2017a). Freshwater Flow to the San Francisco Bay-Delta Estuary Over Nine Decades; Part 1- Trend Evaluation, *Hydrological Processes*, http://onlinelibrary.wiley.com/doi/10.1002/hyp.11201/full. Exhibit DWR-1285
- Hutton, P.H., J.S. Rath, and S.B. Roy (2017b). Freshwater Flow to the San Francisco Bay-Delta Estuary Over Nine Decades Part 2-Change Attribution, *Hydrological Processes*, http://onlinelibrary.wiley.com/doi/10.1002/hyp.11195/full. Exhibit DWR-1286
- Andrews, S., Gross, E., and Hutton, P.H. (2017). Modeling Salt Intrusion in the San Francisco Estuary Prior to Anthropogenic Influence, *Continental Shelf Research*, http://dx.doi.org/10.1016/j.csr.2017.07.010 Exhibit DWR-1287
- Rath, J. S., Hutton, P. H., L. Chen, and S. B. Roy (2017). Modeling Salinity in the San Francisco Bay-Delta Estuary using Artificial Neural Networks, *Environmental Modelling and Software*, http://doi.org/10.1016/j.envsoft.2017.03.022. Exhibit DWR-1288
- Hutton, P.H., Rath, J.S., Chen, L., Ungs, M.J., and Roy, S.B. (2015). Nine Decades of Salinity Observations in the San Francisco Bay and Delta: Modeling and Trend Evaluation. *J. Water Resour. Plng. Mgmt.*, American Society of Civil Engineers, DOI: 10.1061/(ASCE)WR.1943-5452.0000617. Exhibit DWR-1289
- Fox P., Hutton, P.H., Howes, D.J., Draper, A.J., and Sears, L. (2015). Reconstructing the Natural Hydrology of the San Francisco Bay-Delta Watershed. *Hydro. & Earth System Sciences* 19:4257–4274. Exhibit DWR-1290
- Howes, D.J., Fox, P., Hutton, P.H. (2015). Evapotranspiration from Natural Vegetation in the Central Valley of California: Monthly Grass Reference-Based Vegetation Coefficients and the Dual Crop Coefficient Approach. *J Hydrol. Eng.*, American Society of Civil Engineers, DOI: 10.1061/(ASCE)HE.1943-5584.0001162. Exhibit DWR-1291

This new body of work allows for the exploration of longer-term trends and more nuanced interpretation of the effects of drivers (including the CVP-SWP) on Delta flows and salinity. I used this information to develop the opinions provided in this testimony and to rebut opinions provided by others regarding Delta flow and salinity baseline issues.

My opinions build upon previous submittals to the Water Board, including comments provided on the Water Board's 2012 Analytical Tools Workshop and the Bay-Delta Phase II Working Draft Science Report. (See attached exhibits DWR-1363 and DWR-1325.) To

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support many parts of the testimony provided here, I followed a convention utilized in my published manuscripts – and originally adopted by Enright and Culberson (2009) (see attached exhibit DWR-1381) – that classifies the historical data record into two subintervals – a pre-WY 1968 subinterval and a post-WY 1968 subinterval. My use of this convention is intended as an intuitive device for aligning observed data trends with known hydrologic drivers of change.

A brief summary of my opinions is provided below:

- Delta outflow shows no statistically significant volumetric long-term annual time trend.
- Data outflow shows statistically significant increasing and decreasing volumetric long-term seasonal time trends.
- A long-term increasing trend (i.e. higher salinity) in fall X2 has not occurred.
- Long-term trends in fall X2 can be attributed to multiple drivers.
- Under natural conditions, Delta salinity was more seasonally variable than under contemporary conditions, with more downstream X2 in winter and spring and more upstream X2 in summer and fall.
- Delta conditions in the late 19th and early 20th century do not represent natural conditions.
- Unimpaired flow is not an appropriate measure of natural flow on the valley floor or in the Delta.
- Natural conditions cannot be restored using the unimpaired flow hydrograph.

II. DELTA OUTFLOW TIME TRENDS

The 2010 Flow Criteria Report and the Phase II Scientific Basis Report suggest that the magnitude and timing of outflow has changed significantly over time, as evidenced by the difference between calculated unimpaired outflows and actual outflows. My opinions on long-term Delta outflow annual and seasonal trends is provided below.

A. DELTA OUTFLOW SHOWS NO STATISTICALLY SIGNIFICANT VOLUMETRIC LONG-TERM ANNUAL TIME TREND

The Protestants cited the Phase II Scientific Basis Report (Chap. 1.2.2) information that indicates the recent decline of several native estuarine fish species is attributed in part to flow modifications due to dams, water diversions and related operations. The Report cites research that concludes: i) flow modifications greater than 20 percent likely result in

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moderate to major changes in natural structure and ecosystem function; and, ii) water quality and fish resources deteriorate beyond their ability to recover when annual water withdrawals exceed 40–50 percent of unimpaired flow. Contrary to the Phase II Scientific Basis Report, my opinion is that although contemporary upstream diversions and water exports have increased relative to 1920-level conditions, the Delta outflow data shows no statistically significant long-term annual time trend due to overwhelming climatic variability.

My analysis indicates that a statistically significant increasing or decreasing volumetric trend in Delta outflow is not observed on an annual basis. As shown in the left column of Figure 1, annual outflow trends are nominally increasing for the WYs 1922-1967 sub-interval and nominally decreasing for the WYs 1968-2015 subinterval and for the full nine-decade (WYs 1922-2015) period.

Exports show a significant increasing trend for all three periods while inflows do not show significant changes. However, the two sub-intervals are contrasted by a nominal increasing inflow trend over the earlier period and a nominal decreasing inflow trend over the later period.

As shown in the middle column of Figure 1, Sacramento Basin depletions show a decrease in volume (positive sign of trend) over the WYs 1968-2015 subinterval and an increase in volume over the WYs 1922-1967 subinterval and the full nine-decade record, the latter being statistically significant. Sacramento Basin depletions represent net water use within the basin.
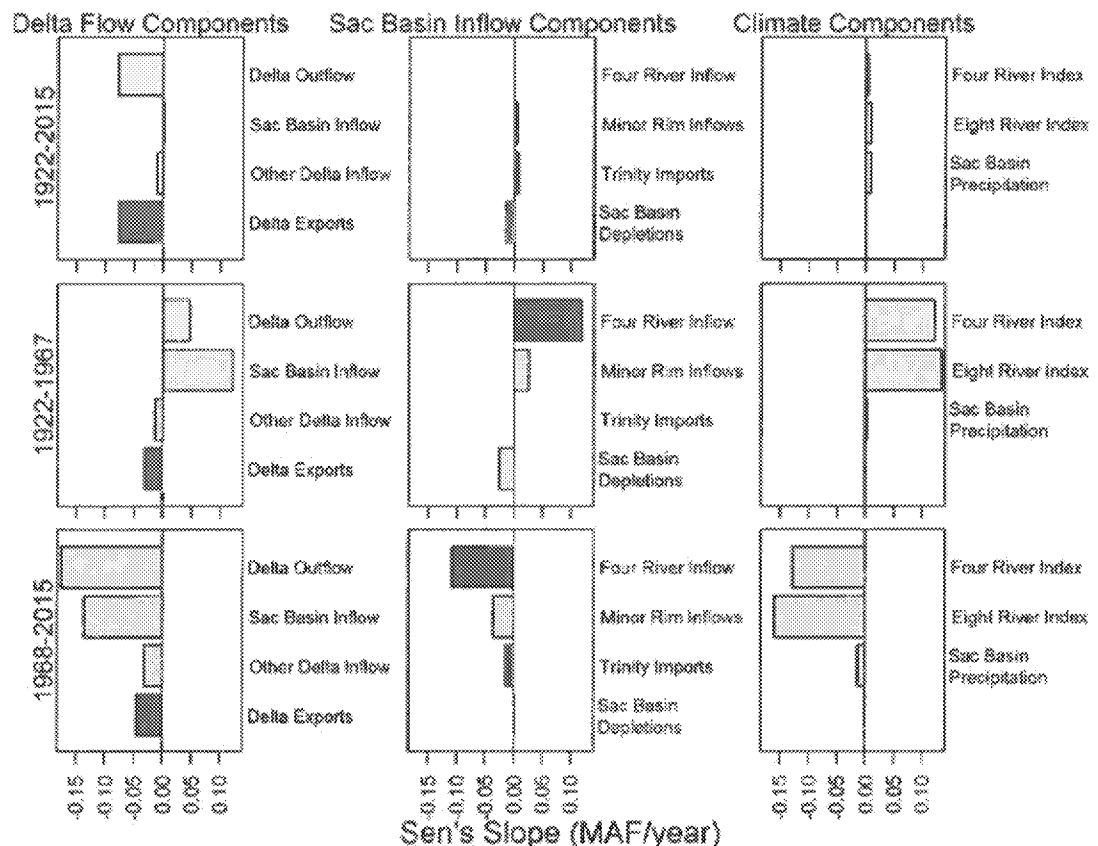
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Figure 1. Summary of annual trend results. The Sen slope estimates are shown on the x-axis. A statistical significance at *p*<0.05 level is shown by blue bars; gray bars indicate statistical significance at *p*≥ 0.05. Results are shown for three time periods: the entire period of record (WYs 1922-2015); the earlier sub-period when many reservoirs were constructed (WYs 1922-1967); and the most recent sub-period following completion of water export infrastructure (WY 1968-2015). Increasing volumes of Delta Exports and Sacramento Basin Depletions are shown as negative trends. (from Exhibit DWR-1285)

The absence of a statistically significant trend in annual Delta outflow over WYs 1922-2015 is counterintuitive given the growth in exports and Sacramento Basin depletions over this period. This finding may be explained in part by the large inter-annual hydrologic variability that masks underlying changes. I evaluated the extent that this variability may mask changes.

Annual Delta outflow trend was further explored by decomposing or deconstructing the time series (shown in the top or first panel of Figure 2) into several components, each representing different categories of patterns. The figure shows a decomposition of the Delta outflow time series into intra-annual "seasonal" component (second panel) and a long-term

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inter-annual "trend" component (fourth panel). The third panel, which repeats the fourth

panel at a magnified scale, reveals a small non-monotonic (changing) long-term trend that

increases through the mid-1960s and gradually declines thereafter. At this magnified scale,

the decomposed trend component confirms the statistical analysis described above and

shown in Figure 1 by revealing nominal increasing and decreasing subinterval trends in

Delta outflow. Finally, decomposition reveals a relatively large "remainder" component

(bottom or fifth panel) that cannot be explained by either the seasonal signal or the trend.

Taken in its entirely, results from the decomposition demonstrate that the Delta outflow

trend is small relative to overwhelming climatic variability.

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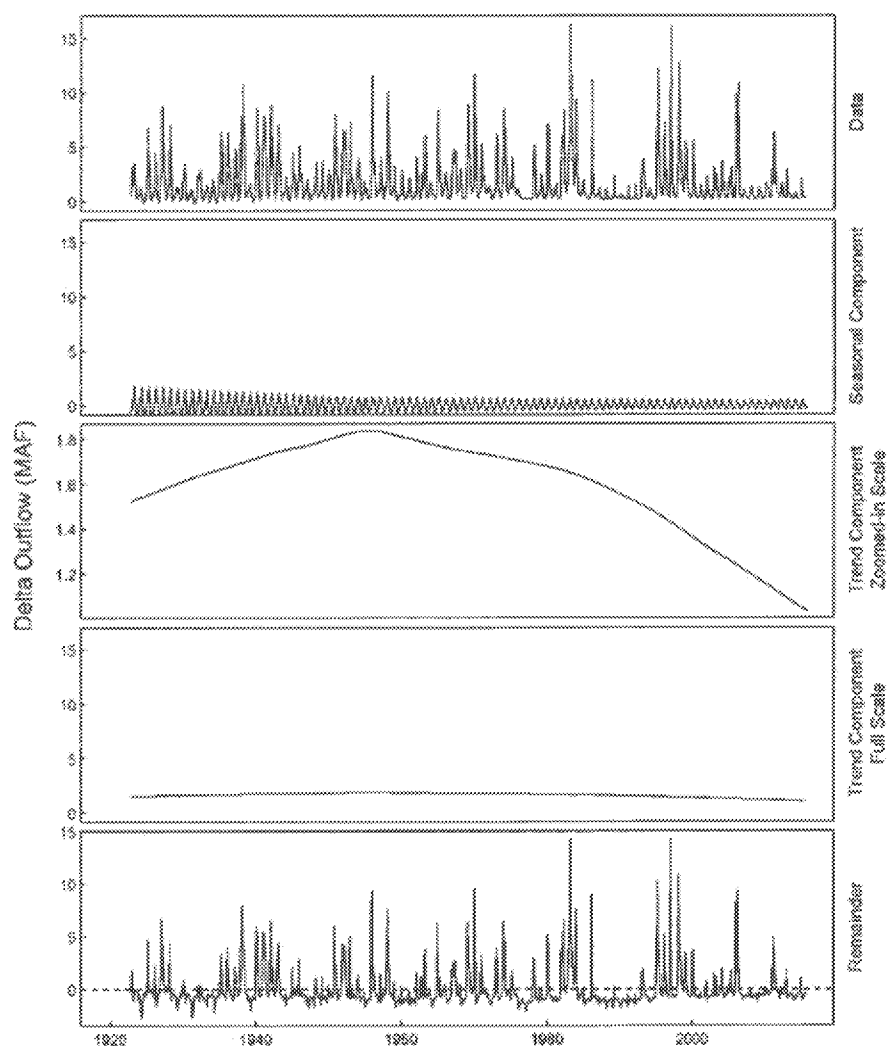
Figure 2. Seasonal trend decomposition test results for Delta outflow. The top panel shows the time series of outflow, and the remaining panels show a decomposition of the flow into "seasonal", "trend", and "remainder" components. The trend component, which is distinct from the trend test result reported in Figure 1, shows a slight increase in Delta outflow between WYs 1922 and 1960 and a slight decrease thereafter. The trend component is shown in two panels (with different y-axis scales) to emphasize both its change and its relative magnitude. (from Exhibit DWR-1285)

To partially filter the climate signal from the annualized flow analysis, the Delta outflow time series was further evaluated by normalizing flow terms with the annual Eight River Index. A statistically significant downward trend was detected for normalized Delta outflow over WYs 1922-2015, largely reflecting growth in exports and Sacramento Basin depletions over this period. Figure 3 shows Delta outflow (upper panel), exports (middle panel), and Sacramento Basin depletions (bottom panel) normalized by the Eight River Index and divided into two subsets: wetter years with the index above 20 MAF and drier years with the index at or below 20 MAF. Smoothing functions are drawn through these points to aid interpretation of the normalized data. With this aid, the data indicate the magnitude of normalized Delta outflow is smaller in drier years and is characterized by a decreasing trend for both subsets.

Importantly, the dry year declining trend stopped or even reversed in the 1980s. This change in trend can be explained in part by normalized export trends (middle panel). Between the 1950s and the 1980s, normalized exports increased for both data subsets. However, in response to Delta flow and salinity regulations, normalized exports have decreased in drier years since the 1980s.

The change in dry year Delta outflow trend can also be explained by normalized Sacramento Basin depletions (bottom panel), which displays a change in trend since the 1980s likely in response to a stable trend in irrigated land use. Note that increasing normalized volumes of Delta exports and Sacramento Basin depletions are shown as negative trends in Figure 3.
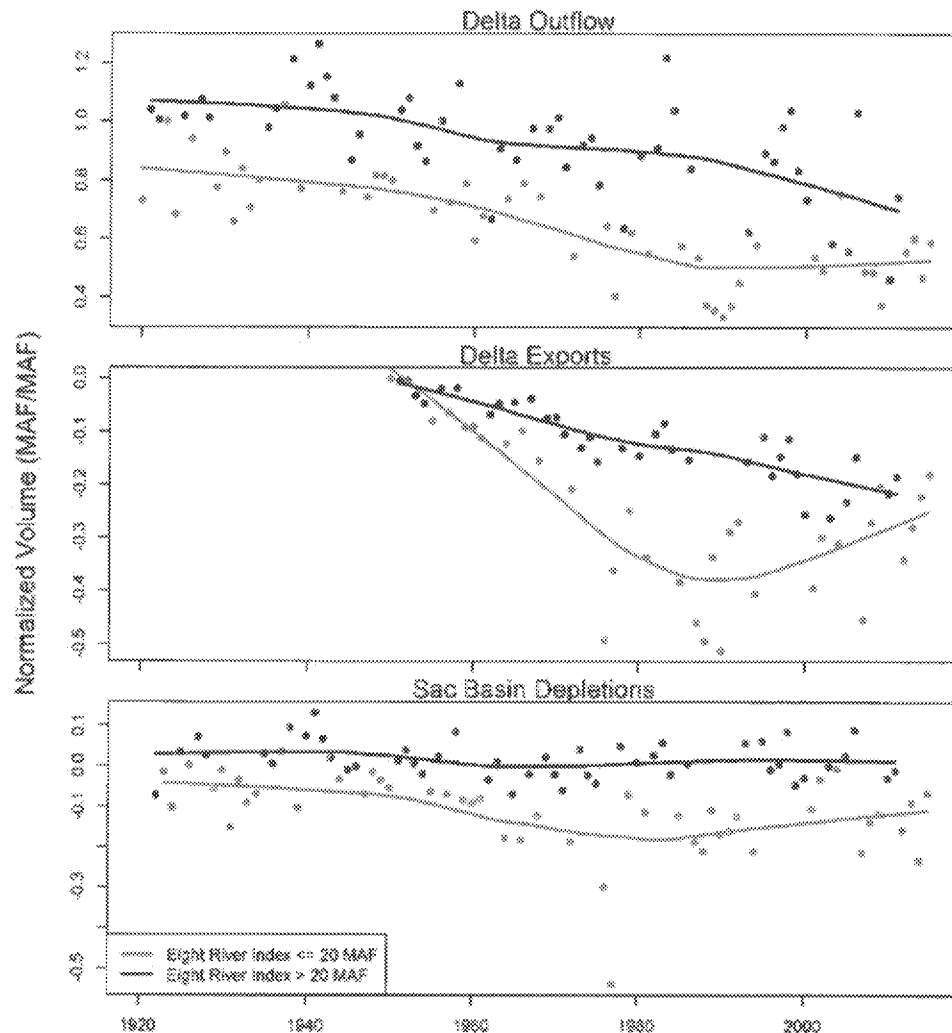
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Figure 3. Annual time series of Delta outflow (upper panel), exports (middle panel), and Sacramento Basin net channel depletions normalized to the Eight River Index (lower panel). The trend lines through the points are smoothing functions as described in the text. In drier years, the downward trend in normalized Delta outflow appears to have been curbed (and possibly reversed) over the last few decades due to more restrictive water management (i.e. lower normalized Delta exports) in the estuary and a leveling of water use in the upstream watershed (i.e. flat trend in Sacramento Basin net channel depletions). Increasing volumes of Delta Exports and Sac Basin Depletions are shown as negative trends. (from Exhibit DWR-1285)

B.   DELTA OUTFLOW SHOWS STATISTICALLY SIGNIFICANT INCREASING AND DECREASING VOLUMETRIC LONG-TERM SEASONAL TIME TRENDS

The Phase II Scientific Basis Report (p. 2-1) provides several statements related to long-term seasonal time trends. For example, the report states that winter and spring outflows have been reduced. Elsewhere, the report states that there has been a reduction in spring outflow since the 1990s due largely to the combined effects of exports, diversions

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and variable hydrology (p. 2-76; p. 5-21). Testimony in PCFFA-145 states that "Very significant reductions in spring flows exist during all water year types, particularly in April and May." It is my opinion that Delta outflow does in fact show statistically significant long-term seasonal time trends. But contrary to the broad statements provided in the Phase II Scientific Basis report, I believe these trends are much more nuanced and are best evaluated on a month by month basis.

Statistically significant outflow trends, shown in the top panels of Figure 4 as both increasing and decreasing, were found in six of the twelve months over the full WYs 1922-2015 period: February (decreasing), April (decreasing), May (decreasing), July (increasing), August (increasing) and November (decreasing). Full period trends observed in April and May likely correspond to increases in upstream storage in reservoirs, as suggested by the significant decreases in Sacramento Basin inflow shown in the second panel of Figure 4. Contrary to the full period trend, subinterval trends in April and May Delta outflow are not significant. And in contrast with the Phase II Report statement about decreasing spring flows since the 1990s, Delta outflow in May and June has exhibited a nominally increasing trend in the WY 1968-2015 subinterval. Significant Delta outflow increases in July and August over the full period are likely related to increased reservoir releases to meet export needs and salinity objectives in the Delta, as suggested by the significant increases in Sacramento Basin inflow in these months.

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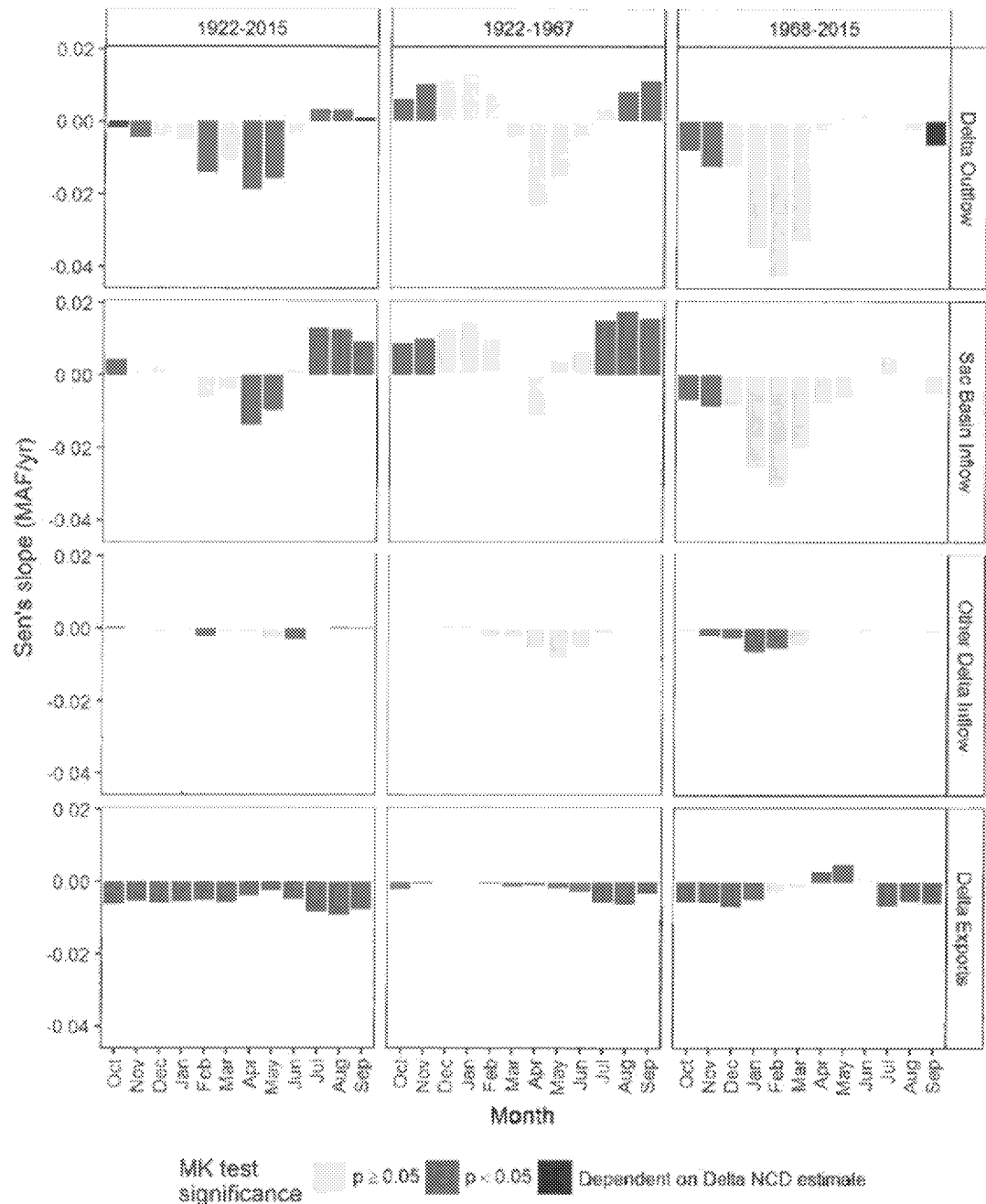
Figure 4. Monthly trends and Sen slopes for Delta flow components. A statistical significance at $p<0.05$ level is shown by blue bars; gray bars indicate statistical significance at $p \geq 0.05$. Results are shown for three time periods: the entire period of record (WYs 1922-2015); the earlier sub-period when many reservoirs were constructed (WYs 1922-1967); and the most recent sub-period following completion of water export infrastructure (WY 1968-2015). Increasing volumes of Delta Exports are shown as negative trends. (from Exhibit DWR-1285)

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III. FALL X2

Both the 2010 Flow Criteria Report and the Phase II Scientific Basis Report propose a fall X2 requirement that is fully consistent with the USFWS 2008 Biological Opinion. To place the fall X2 trends presented in my testimony in proper context, it is important to recognize that these trends have not been influenced by the 2008 Biological Opinion's fall X2 actions. My testimony on fall X2 focuses on hydrology-based rationale presented in the Biological Opinion.

The fall X2 action, which is to be imposed in months following wet and above normal water years, did not impact CVP-SWP water project operations over the period of record I evaluated (WYs 1922-2012). In WY 2011 (a wet year) the action was partially adjusted in response to a federal court order and the modified criteria, although it was ultimately met without changing operations. In 2017, the USFWS authorized a relaxation of the requirement.[1]

A. A LONG-TERM UPSTREAM SHIFT IN FALL X2 HAS NOT OCCURRED

Contrary to the Biological Opinion, my opinion is that a long-term upstream shift in fall X2 has not occurred. The basis for my opinion is discussed below.

The salinity time series of individual fall months over WYs 1922-2012, developed in Exhibit DWR-1289, are examined by water year type corresponding to the prior spring (Figures 5, 6 and 7). X2 values exhibit unique trends for each fall month. There is a decrease in X2 (more downstream with greater freshwater flows) in September after the mid-1940s, corresponding to an altered flow regime following construction of Shasta Reservoir in 1944. In September, the post-Shasta X2 values are more downstream than pre-Shasta values, especially following wet and above normal years. October X2 exhibits a small downstream trend from the 1920s through the 1960s, followed by a small upstream

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[1] This context is not acknowledged in the CCC-SC 03 testimony that states that since the introduction of the fall X2 actions, degradation in fall X2 salinity during 1995-2008 appears to have reduced.

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trend from the 1960s through the 1980s, with minimal trend in the latter part of the record. The November X2 time series exhibits a downstream trend from the 1920s through the 1960s, an upstream trend from the 1960s through the 1980s, and a relatively stable trend thereafter.
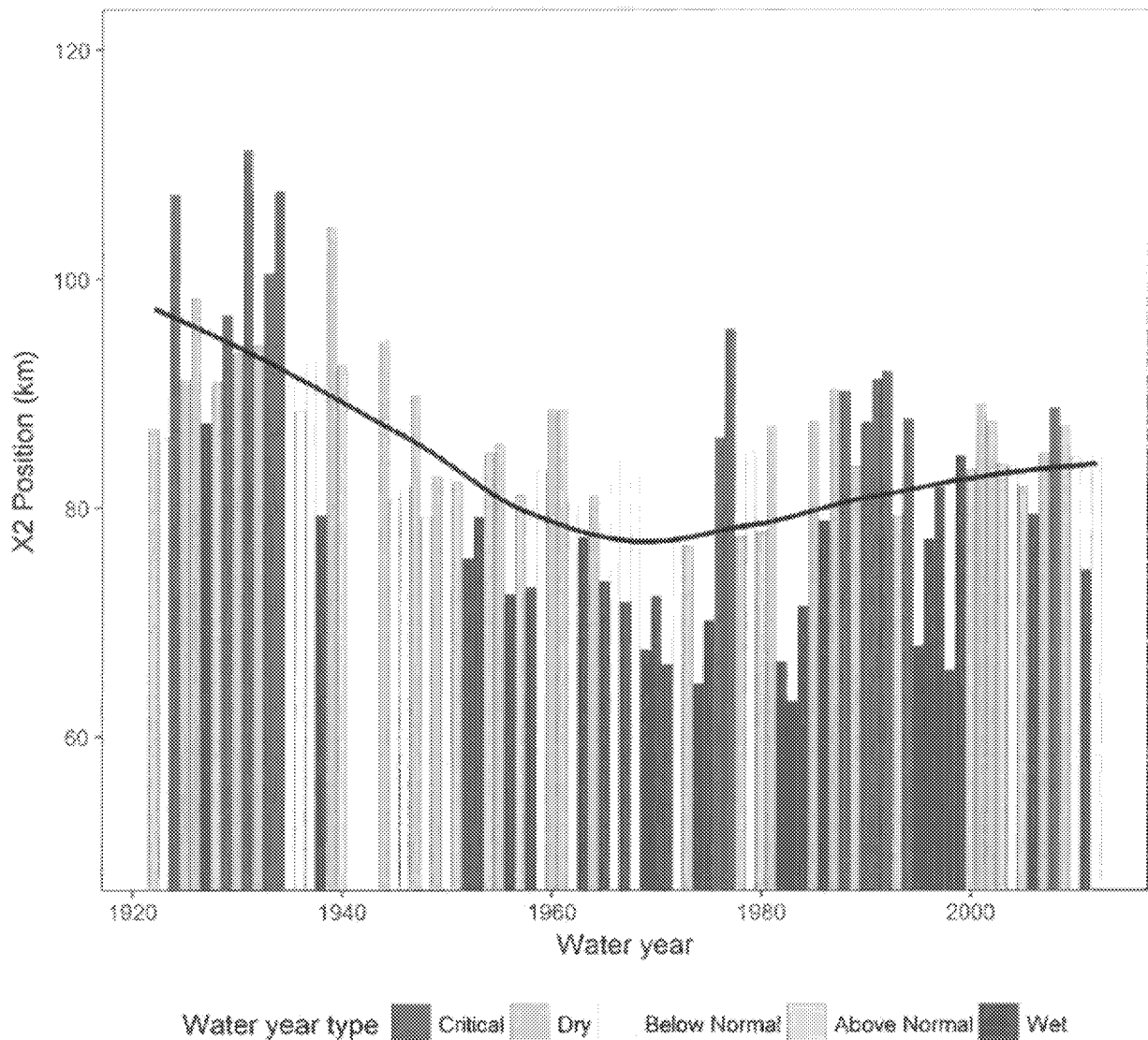
Figure 5. September X2 values and associated 40-30-30 water year type for WYs 1922-2012. The black curve is a smoothing function to the X2 observations. (Based on Exhibit DWR-1289)
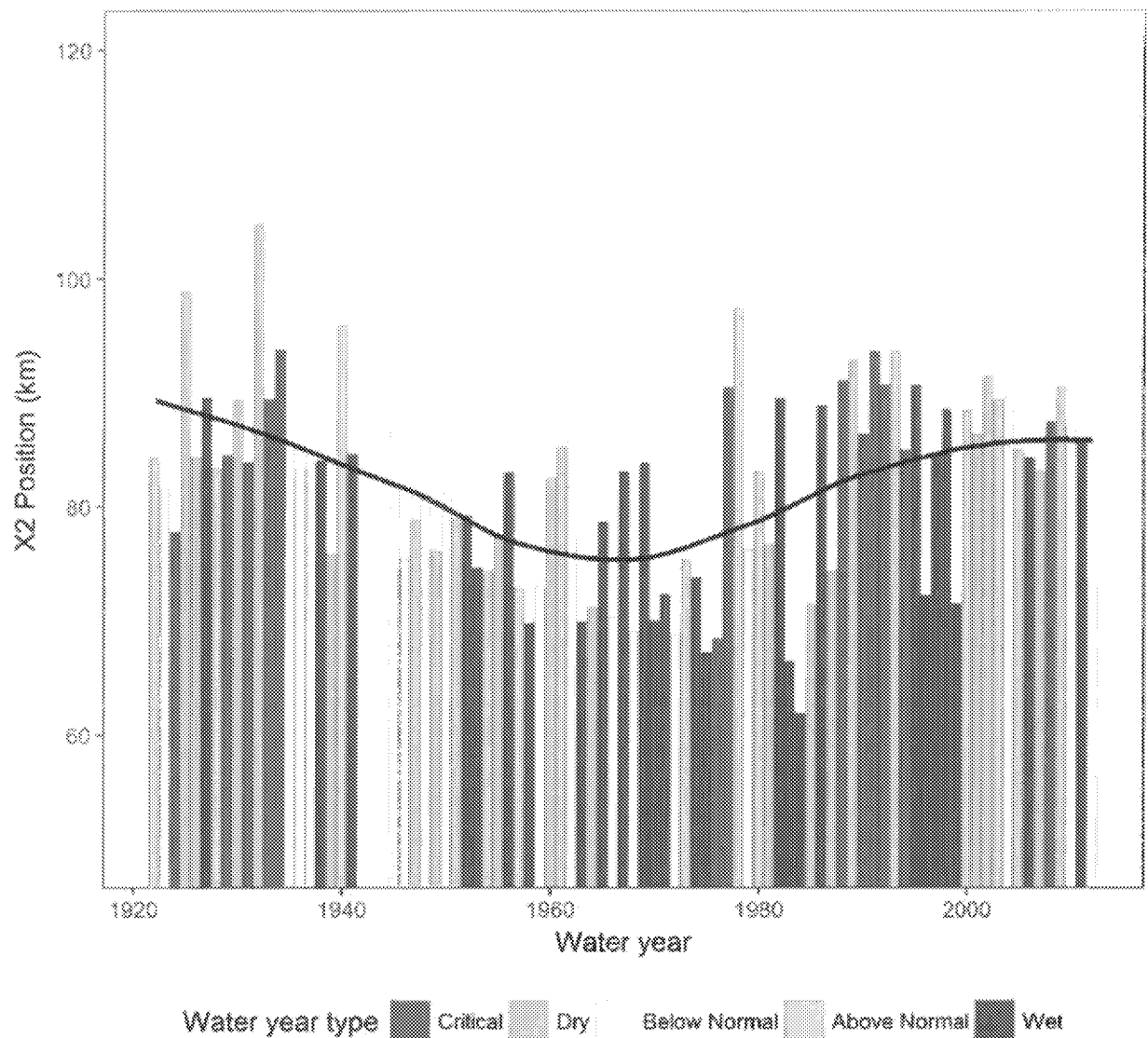
Figure 6. October X2 values and associated 40-30-30 previous water year type for WYs 1922-2012. The black curve is a smoothing function to the X2 observations. (Based on Exhibit DWR-1289)
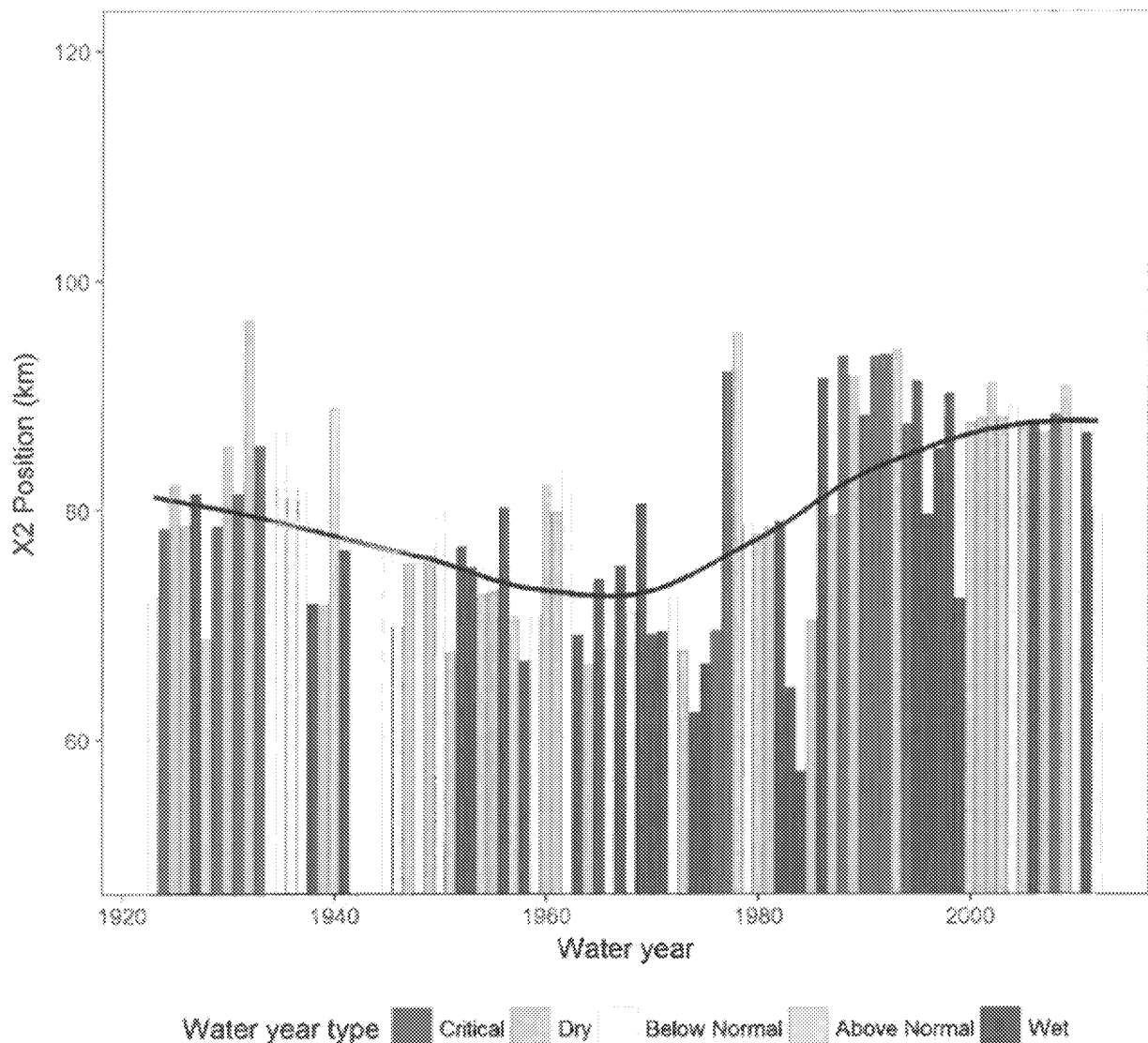
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Figure 7. November X2 values and associated 40-30-30 previous water year type for WYs 1922-2012. The black curve is a smoothing function to the X2 observations. (Based on Exhibit DWR-1289)

The 2010 Flow Criteria Report (p. 109) states that the USFWS fall X2 action "...is focused on wet and above normal years because these are the years in which project operations have most significantly affected fall outflows." Contrary to this statement, Exhibit DWR-1289 shows that X2 trends in October and November following above normal and wet years are nominal upstream but are not statistically significant. (Exhibit DWR-1289 shows X2 trends in September in above normal and wet years are downstream (fresher) and are statistically significant.)

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In summary, over the full period of record there has been a statistically significant long-term downstream trend in September, no long-term trend in October, and a statistically significant long-term upstream trend in November. Thus, it is my opinion that the full period of record does not support the finding of a broad long-term increase in fall X2.

B.   LONG-TERM TRENDS IN FALL X2 CAN BE ATTRIBUTED TO MULTIPLE DRIVERS

As shown in my analysis, long-term trends in fall X2 can be attributed to multiple drivers. The basis for my opinion is discussed below.

To evaluate the relationship between CVP-SWP operations and fall X2 in a rigorous manner, I looked at the behavior of Delta outflow and X2 under two different hypothetical scenarios (i.e. 1920 level of development and without-Project) and compared these scenarios with historical conditions to directly attribute changes to specific drivers. The methodology associated with this attribution analysis is documented in Exhibit DWR-1286. This evaluation shows that Project operations, which include a combination of reservoir and export operations, have caused changes in fall outflow (Figure 8) and X2 (Figure 9) that vary by month and time period. Furthermore, this evaluation shows that other drivers such as non-Project storage and diversions, i.e. non-Project drivers, also contribute to changes in fall outflow and X2. Changes in X2 that are attributable to the CVP-SWP are shown for individual fall months in Figure 10.

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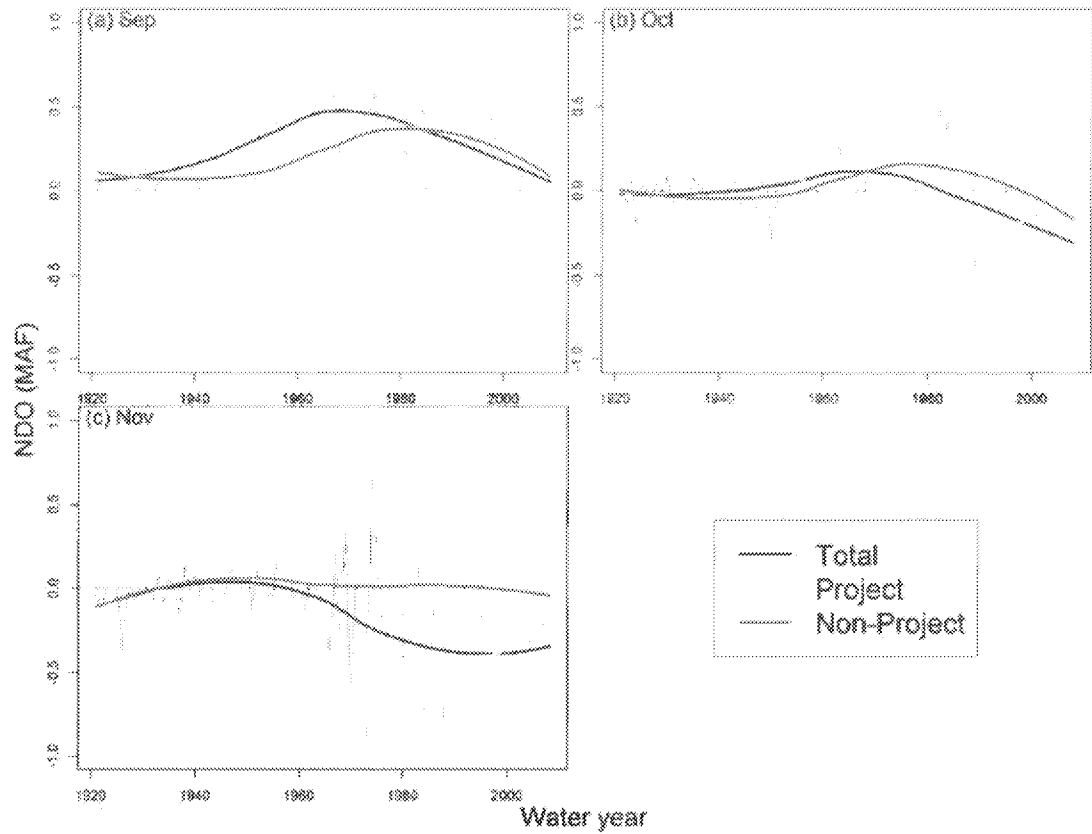
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Figure 8. Attribution of WY 1922-2009 Delta outflow changes to Project (CVP-SWP) and non-Project effects for the fall months of (a) September, (b) October, and (c) November. Total outflow changes are measured relative to a 1920 level of development baseline.
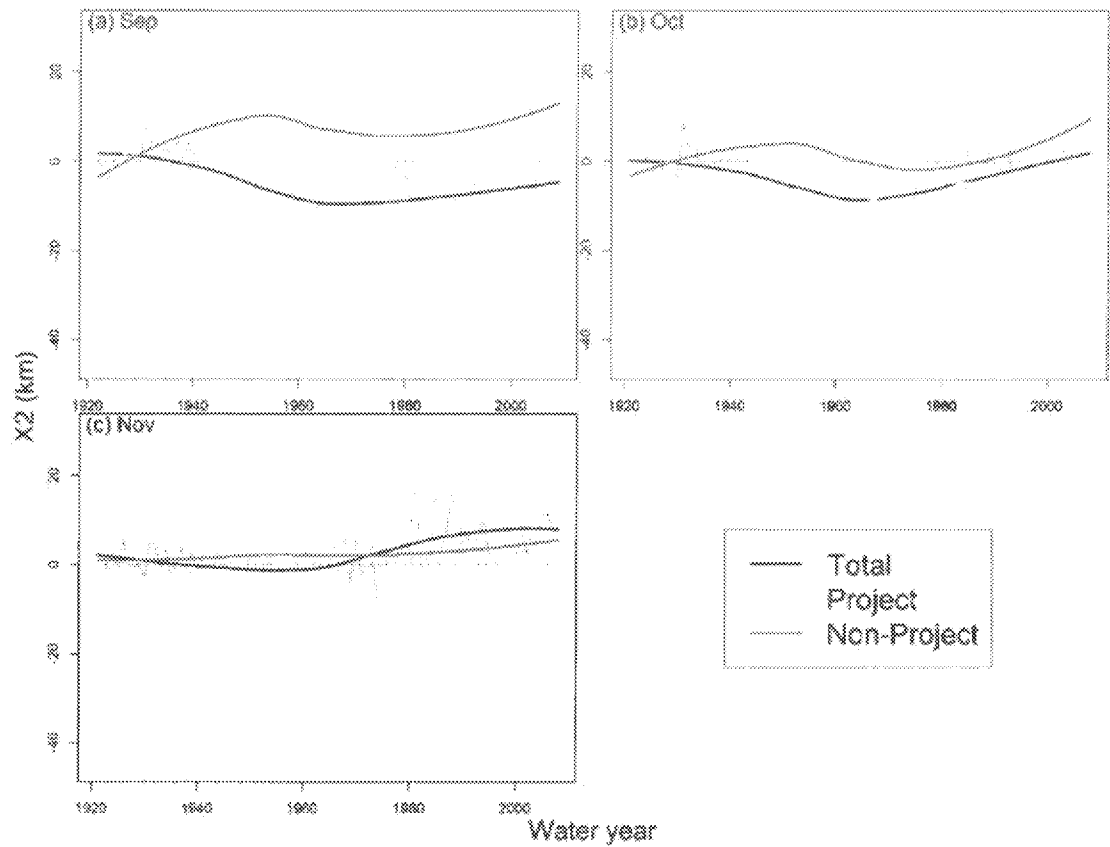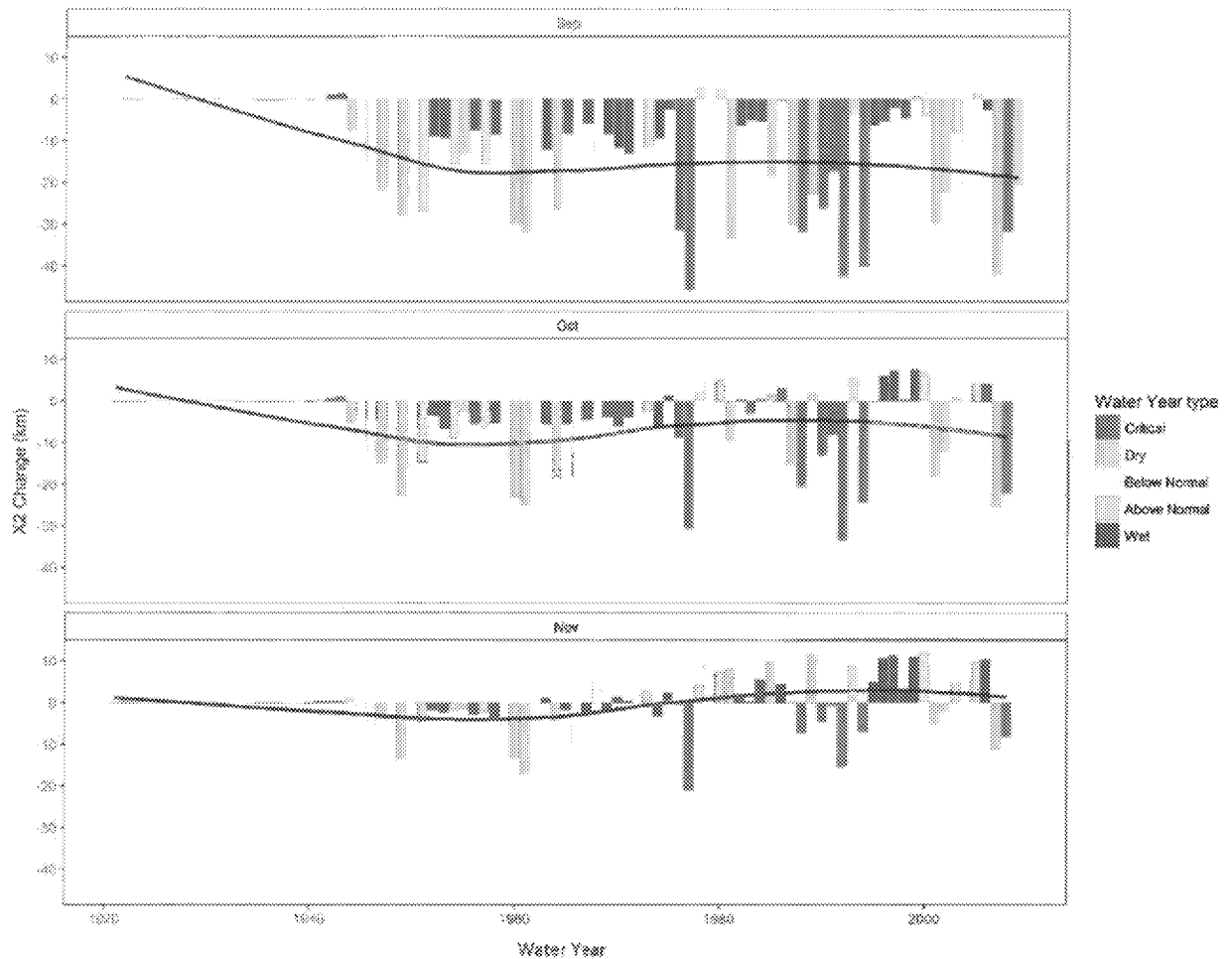
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Figure 9. Attribution of WY 1922-2009 Delta X2 changes to Project (CVP-SWP) and non-Project effects for the fall months of (a) September, (b) October, and (c) November. Total X2 changes are measured relative to a 1920 level of development baseline.

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Figure 10. Attribution of WY 1922-2009 Delta X2 changes to Project (CVP-SWP) effects for the fall months by 40-30-30 water year type for the Sacramento Valley. The black curve is a smoothing fit of the X2 changes.

For the month of September, Project effects have resulted in an outflow increase in the early part of the record and a decrease in the latter part of the record, resulting in little overall change over the full period of record. The X2 trend attributed to the Projects shows a decrease in the early part of the record and remains flat in the latter part of the record, resulting in a large overall downstream trend in X2 over the full period of record. Differences between outflow and X2 effects are due to antecedent effects of outflow on salinity. Project effects more than compensate for non-Project effects, which in isolation result in decreased outflow and increased X2 over the full period of record.

For the month of October, Project effects have resulted in an outflow decrease in the latter part of the record and an overall X2 decrease resulting from antecedent effects.

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Project effects approximately compensate for non-Project effects, which in isolation result in decreased outflow and increased salinity over the full period of record.

For the month of November, Projects effects have contributed to decreasing outflow and increasing X2 over the full period of record. While the Projects have the most significant effect on November outflow, non-Project drivers have similar or greater effect on November X2. As in the other fall months, differences between outflow and X2 effects are due to antecedent effects of outflow on salinity.

The above analysis, with model-based estimates of Project and non-Project effects, provides a rigorous method of attributing fall outflow and X2 change to key drivers. In summary, while it may be said that CVP-SWP operations are associated with an increase in fall X2 in the month of November, changes in this month are due in equal or greater part to non-Project effects. For the remaining fall months (i.e. September and October), CVP-SWP operations actually result in more downstream X2 and compensate for non-Project effects that would increase fall X2 absent the Projects.

III.C. FALL SALINITY IS VARIABLE AND DOES NOT RESEMBLE DRY YEARS REGARDLESS OF HYDROLOGY

As shown in my analysis, fall X2 is variable and does not resemble dry years regardless of hydrology. The basis for this opinion is discussed below.

I examined variability in fall X2 through a variety of analyses. First, I examined variability in the full X2 record spanning WYs 1922-2012, without differentiating between seasons. In Figure 11, the dark solid lines display ten-year (120 month) moving average X2 at the 10th, 25th, 50th, 75th, and 90th percentiles. The corresponding dotted lines are linear trends for the same percentiles. This data presentation shows a slight decrease in inter-annual variability over time, due primarily to the high X2 values in the early part of the record. These high X2 values do not occur after the construction of Lake Shasta and other CVP-SWP facilities, in part because the Projects are operated to minimize the extensive salt water intrusion that historically occurred prior to the 1940s.
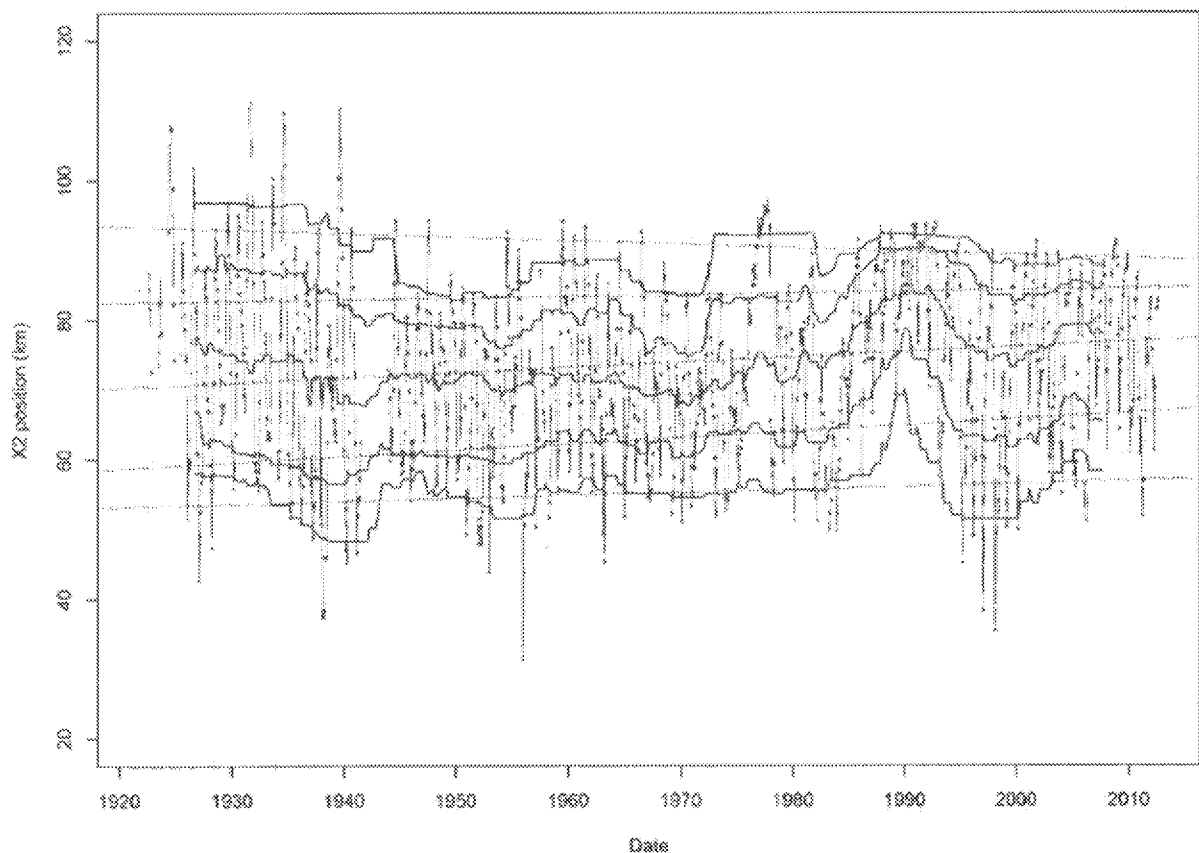
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Figure 11. Variation in Sacramento X2 over WY 1922-2012. The dark solid lines display 120 month moving windows for the 10th, 25th, 50th, 75th, and 90th percentiles. The corresponding dotted lines display linear trends for the same percentiles.

Next, in Figure 12 I examined variability in the X2 record for the three fall months, this time differentiating between months over various time intervals: four shorter subintervals (WYs 1922–1944, WYs 1945–1967, WYs 1968–1999, and WYs 2000–2012); two larger subintervals (WYs 1922–1967 and WYs 1968–2012); and the entire record (WYs 1922–2012). This figure shows how the range in X2 has changed for each fall month. Specifically, the early record (WYs 1922-1944) includes high X2 values in all fall months. The WYs 1945-1967 and WYs 1968-1999 subintervals both show lower fall X2 values relative to WYs 1922-1944. Fall X2 values in WYs 2000-2012 exhibit ranges that are narrow but within the interquartile bounds of the WYs 1969-1999 data; these narrower ranges may be explained at least in part by the small number of data points associated with

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the time interval. Despite this possible explanation, the November range for this period is remarkably narrow relative to other periods.
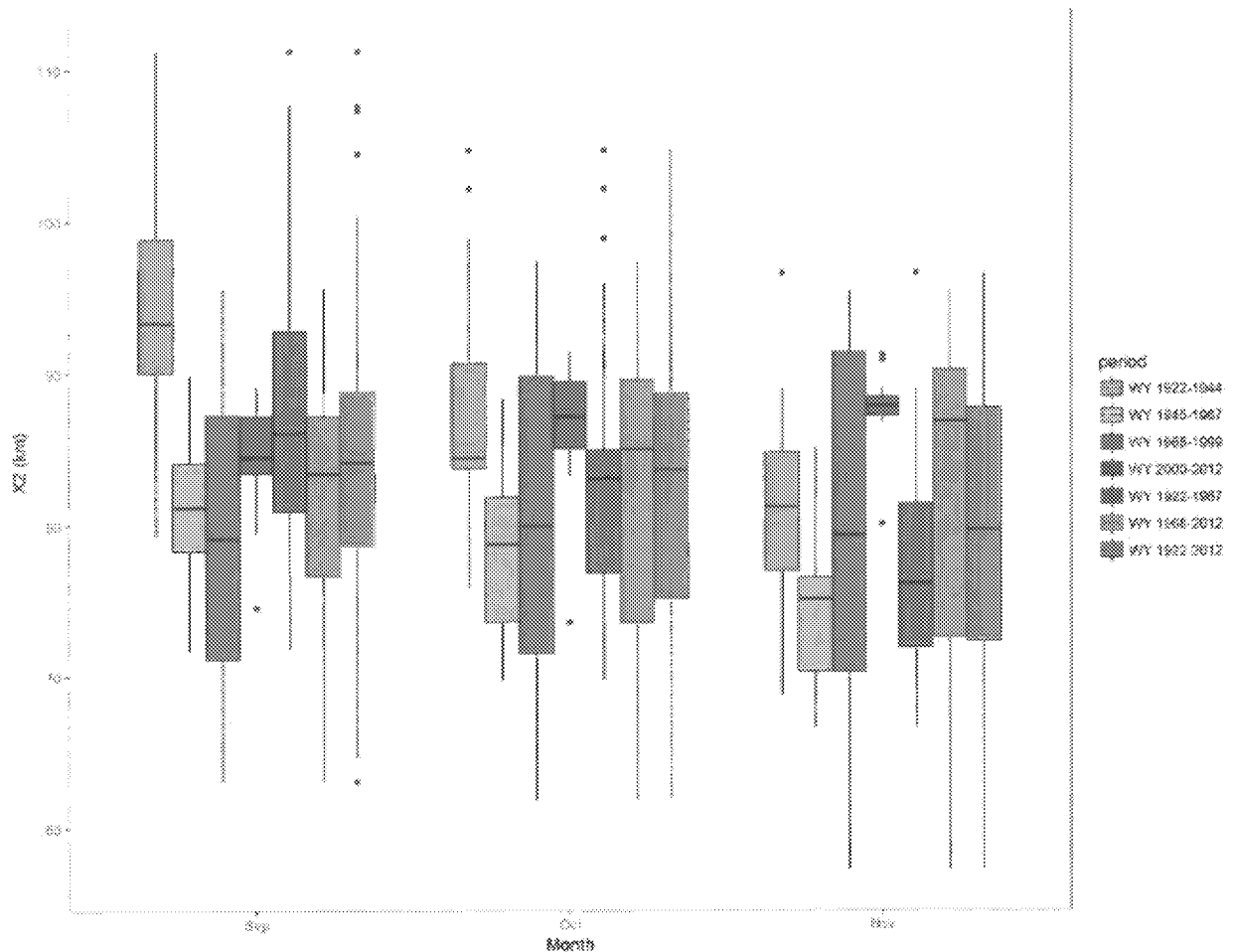
Figure 12. Box plots of Sacramento X2 for various time intervals, including four shorter intervals (WY 1922–1944, WY 1945–1967, WY 1968–1999, and WY 2000–2012), two longer intervals (WY 1922–1967 and WY 1968–2012), and the entire record WY 1922–2012. Each box represents the 25th and 75th percentile values, the line represents the median, and the whiskers extend to the most extreme data point no further than 1.5 times the interquartile range from the box. Outliers are shown as discrete symbols.

In Figure 13 I examined the intra-month variability in fall outflow, expressed as a coefficient of variation of daily values within a given month. This data presentation does not show a decrease in fall variability over time; rather, it shows an increasing trend in flow variability in the months of October and November.

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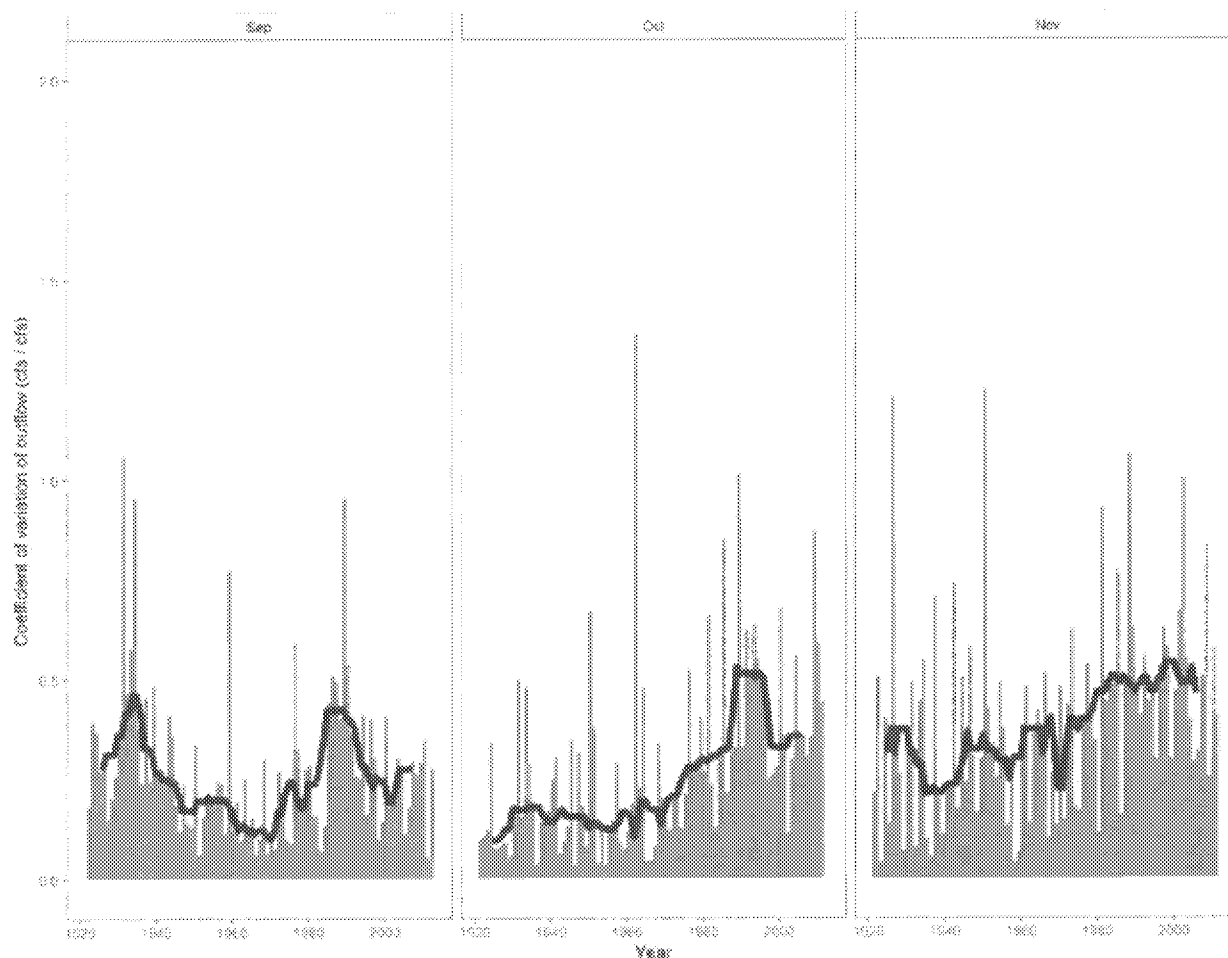
Figure 13. Coefficient of variation (ratio of mean to standard deviation) of daily Delta outflows by month for WY 1922-2012.

Finally, I examined how the relationship between fall X2 and spring hydrology has changed over discrete time intervals and how this change can be attributed to CVP-SWP operations. Figure 14 plots September X2 as a function of spring (April-July) unimpaired runoff under historical (upper panels) and without-Project conditions (lower panels) at four discrete time subintervals: WYs 1922-1944; WYs 1945-1967; WYs 1968-1999; and WYs 2000-2012. For reference, all panels include the relationship between September X2 and spring unimpaired runoff under 1920-level conditions. Without-Project and 1920-level conditions were obtained from Exhibit DWR-1286. Similar plots are provided for October (Figure 15) and November (Figure 16).
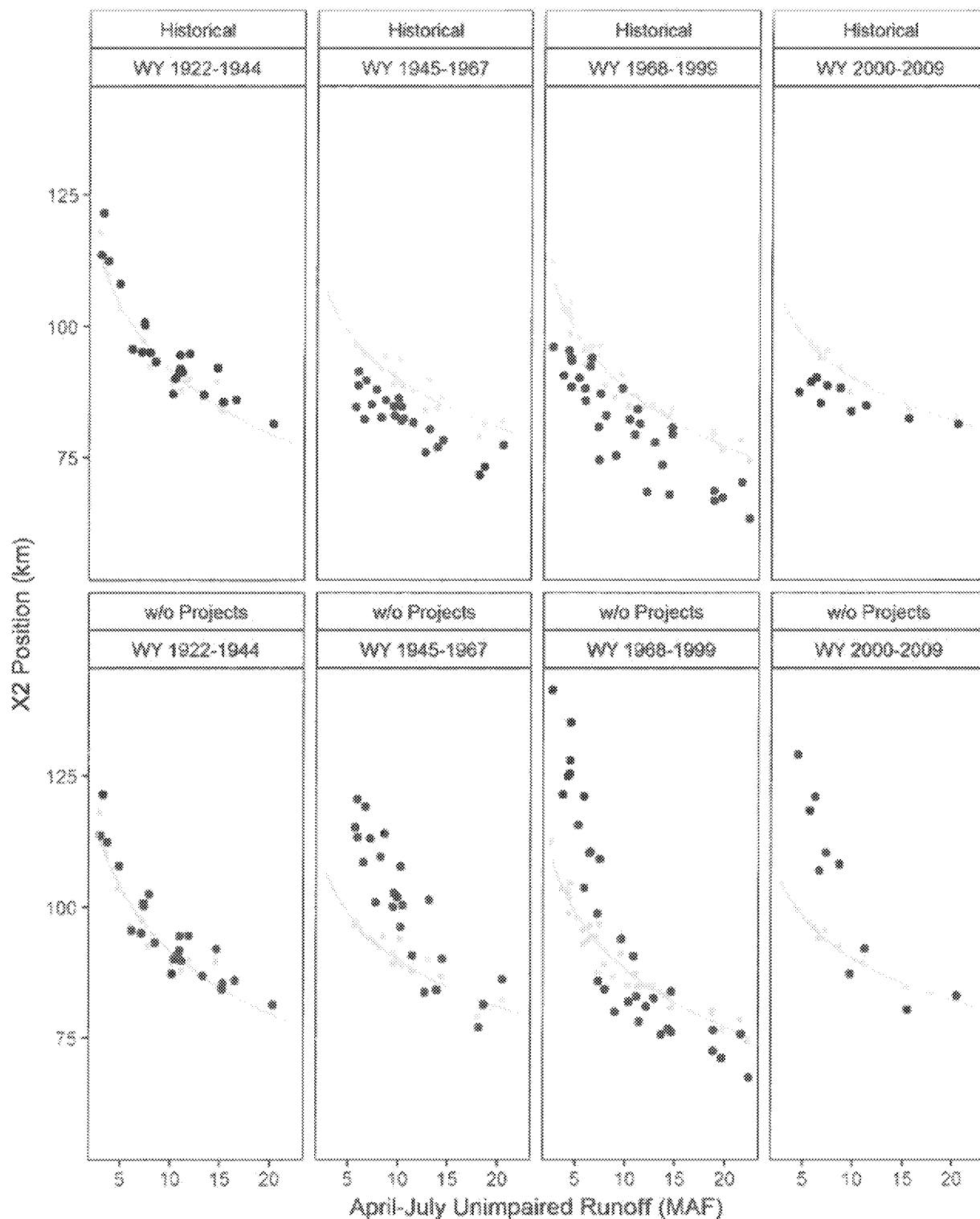
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Figure 14. Comparison of September X2 under historical and without Project conditions as a function of spring (April-July) unimpaired runoff for four time periods: WY 1922-1944; WY 1945-1967; WY 1968-1999; WY 2000-2009. In all plots, corresponding X2 values under 1920 level of development conditions are shown as gray symbols; the gray lines are best-fit curves to the 1920 level data.
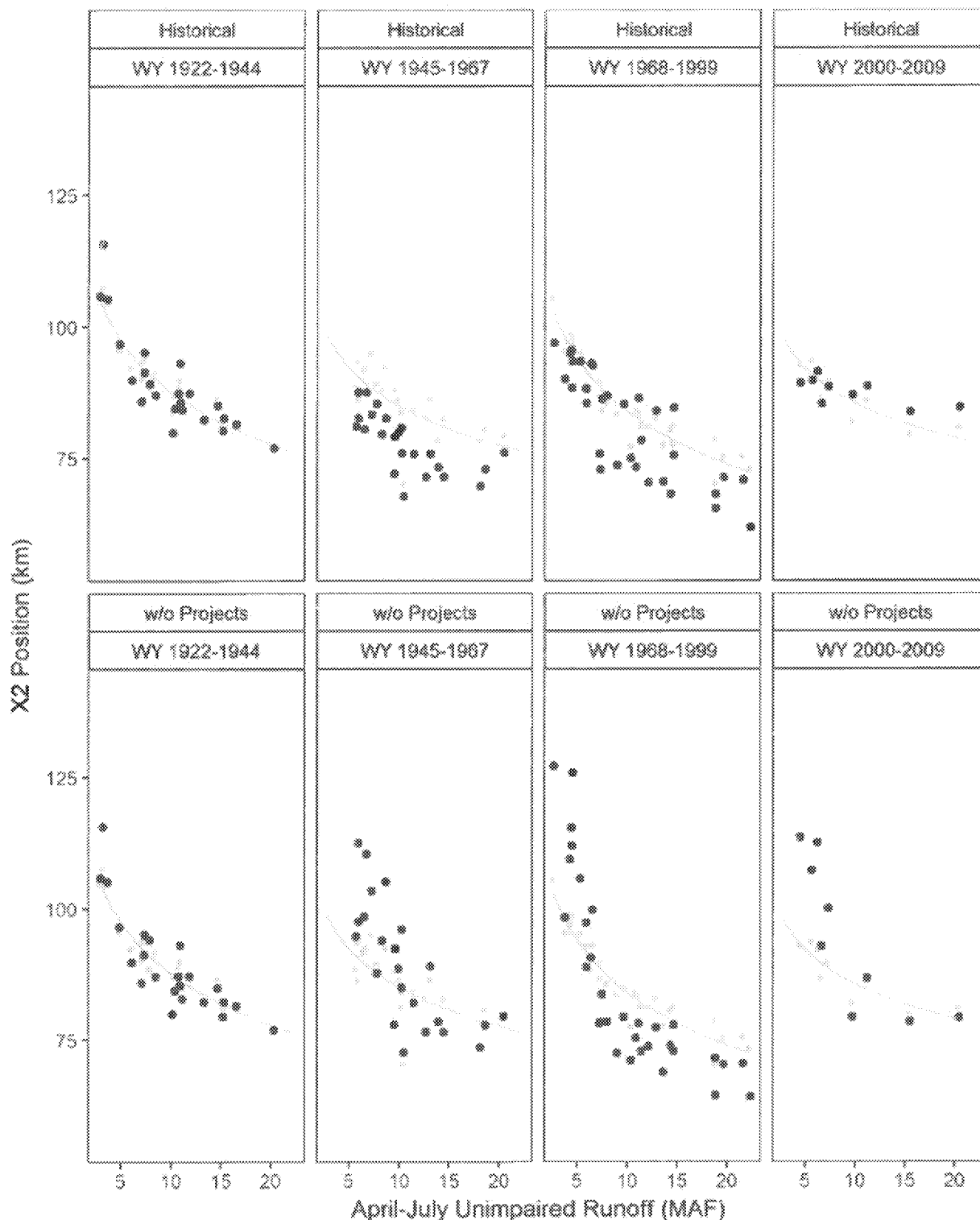
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Figure 15. Comparison of October X2 under historical and without Project conditions as a function of spring (April-July) unimpaired runoff for four time periods: WY 1922-1944; WY 1945-1967; WY 1968-1999; WY 2000-2009. In all plots, corresponding X2 values under 1920 level of development conditions are shown as gray symbols; the gray lines are best-fit curves to the 1920 level data.
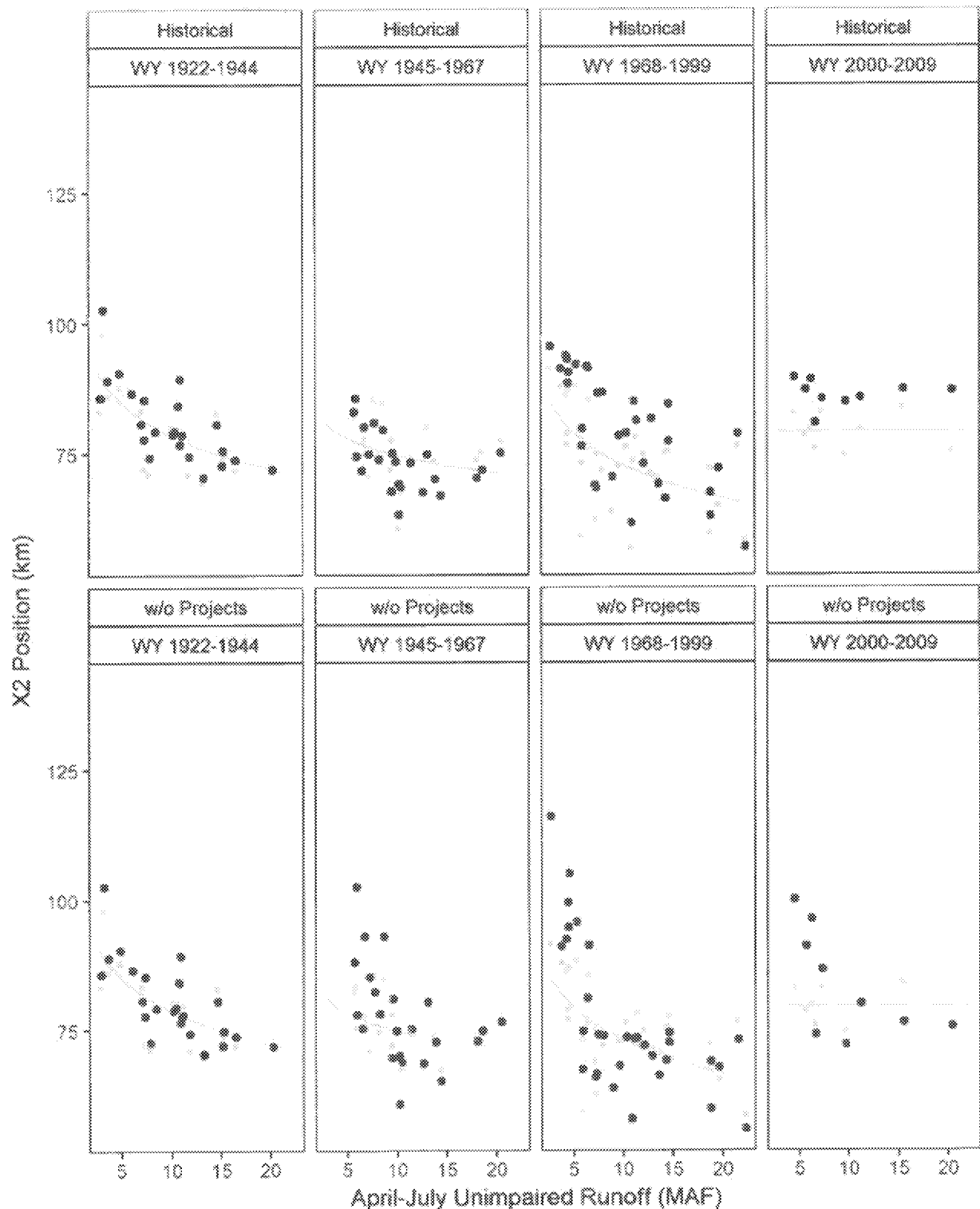
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Figure 16. Comparison of November X2 under historical and without Project conditions as a function of spring (April-July) unimpaired runoff for four time periods: WY 1922-1944; WY 1945-1967; WY 1968-1999; WY 2000-2009. In all plots, corresponding X2 values under 1920 level of development conditions are shown as gray symbols; the gray lines are best-fit curves to the 1920 level data. (The WY 2000-2009 best-fit curve was not statistically significant and is replaced with the sample mean.)

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Close inspection of Figures 14 through Figure 16 suggests that if there has been a loss of inter-annual variability in fall X2, it is not because all fall months now resemble dry year conditions regardless of water year type. On the contrary, these figures suggest that CVP-SWP operations have bolstered dry year outflows such that X2 in the fall (particularly September and October) now resemble average to wetter years. Furthermore, Figure 16 suggests that the narrow range observed in the WYs 2000-09 November X2 range (Figure 12) is not attributed to Project operations; this narrow range is seen in the 1920-level scenario as well as the Without-Project scenario.

When the data are considered in their entirety, assertions regarding loss of fall X2 variability appear to be related to consideration of a truncated data set. When the data are evaluated more broadly and on a month-by-month basis, it does not appear that a loss of variability has occurred in September and October, although there does appear to be some reduction of variability in the November values in the WYs 2000-2012 subinterval that is not attributed to Project operations.

IV. PRE-DEVELOPMENT OR "NATURAL" DELTA CONDITIONS

Understanding pre-development or "natural" Delta flow and salinity conditions is central to the proposals made in the 2010 Flow Criteria Report and the Phase II Scientific Basis Report. While I acknowledge that our understanding of natural Delta conditions is subject to substantial uncertainty, it is my opinion that the 2010 Flow Criteria and Phase II Scientific Basis Reports, as well as several testimonies (See e.g., PCFFA-145, CCC-SC-3, Antioch-500, errata) provided to the Water Board, have not accurately portrayed natural Delta conditions. For example, the Phase II Scientific Basis Report (p. 5-6) states that, while unimpaired flow is not the same as natural flow, it is generally reflective of the magnitude of the natural flows to which fish and wildlife have adapted. This statement is in stark contrast to a finding in DWR (2016) (see attached Exhibit DWR-1384) that under average conditions, the annual unimpaired flow is 43 percent higher than the natural flow

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estimate. My opinion regarding several aspects of natural Delta conditions are discussed below.

A. NATURAL DELTA SALINITY WAS MORE SEASONALLY VARIABLE THAN CONTEMPORARY CONDITIONS, WITH MORE DOWNSTREAM X2 IN WINTER AND SPRING AND MORE UPSTREAM X2 IN SUMMER AND FALL.

The work presented in Exhibits DWR-1287, DWR-1290, DWR-1291 and DWR-1384 is the best available science to quantify estimates of natural Delta hydrology and hydrodynamics. This body of work shows that, under similar climatic conditions, annualized Delta outflow would have been similar or somewhat higher under natural conditions relative to contemporary conditions. These annualized estimates suggest that natural vegetation in the Delta used nearly as much water as is consumed currently for agriculture, municipal, industrial and other uses. This body of work also shows that, under similar climatic conditions, seasonal Delta outflow and X2 would have been more variable under natural conditions relative to contemporary conditions. Specifically, this work suggests that natural conditions were characterized by more downstream (fresher) X2 in winter and spring and more upstream (saltier) X2 in summer and fall. This greater X2 seasonal variability is illustrated in panel (c) of Figure 17.
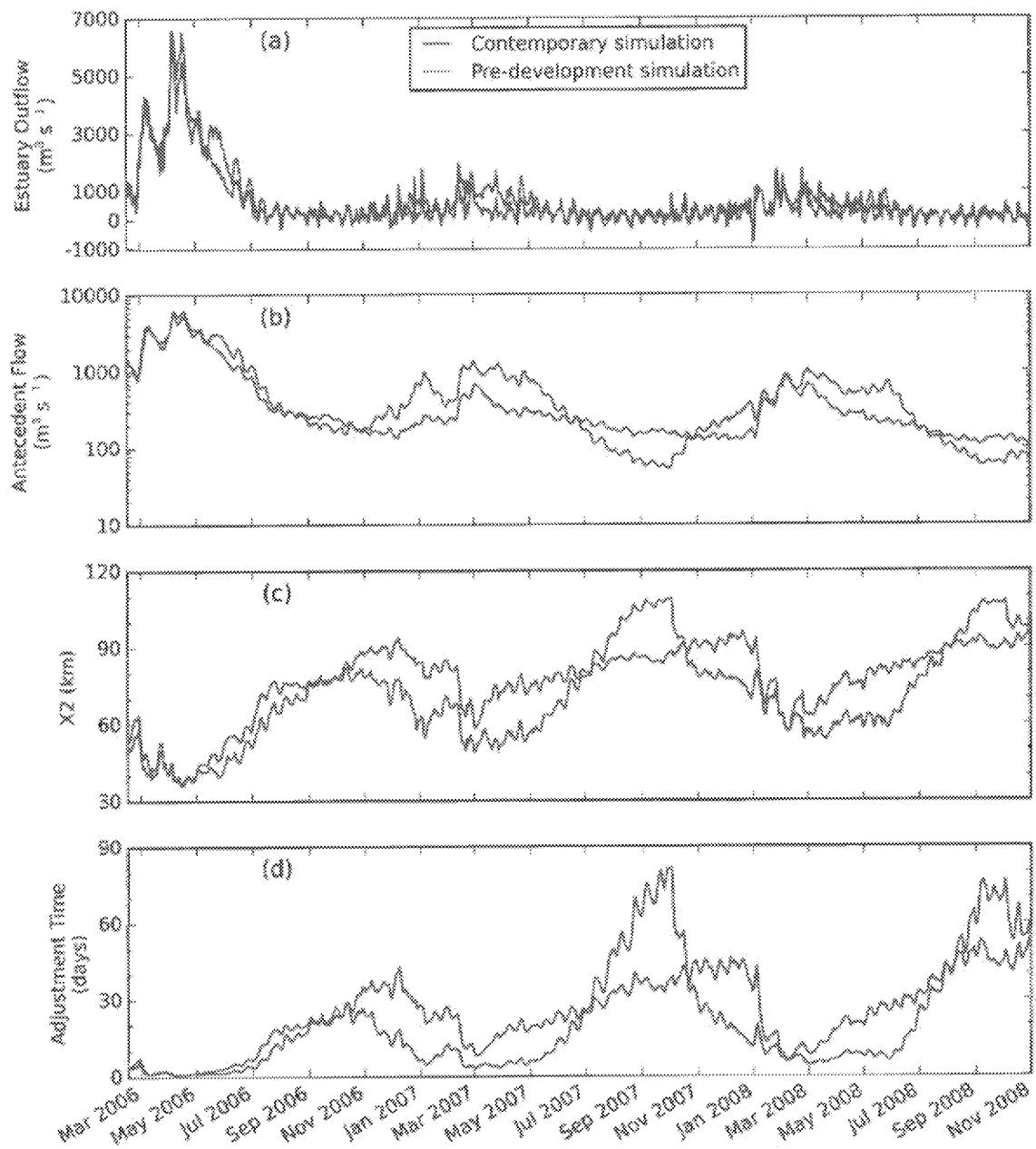
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Figure 17. (a) Model calculated net estuary outflow, (b) antecedent flow, (c) X2, and (d) adjustment time for the contemporary and pre-development estuary simulations. (From Exhibit DWR-1287.)

It is important to emphasize that the quantified estimates of natural flow and salinity are not estimates of actual flow and salinity that occurred under Paleolithic or more recent conditions prior to European settlement. Rather, the quantifications are estimates that assume the contemporary precipitation and inflow pattern to the Delta watershed in a

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natural or undeveloped state: before flood control facilities, levees, land reclamation, irrigation projects, imports, etc.

B. DELTA CONDITIONS IN THE LATTER 19TH AND EARLY 20TH CENTURY PRIOR TO 1917 DO NOT REPRESENT NATURAL CONDITIONS

Dr. Paulsen testified that, in her opinion, the historical record clearly demonstrates that "natural conditions" at Antioch were predominantly fresh prior to 1917 in all but the driest years (Exhibit Antioch-500). She cites the CCWD 2010 report (Exhibit Antioch-216) and the C&H barge travel data to support her opinion. Her testimony assumes that Delta conditions prior to 1917 represent natural conditions. It is my opinion that the Delta salinity conditions were fresher during this period than they are under contemporary conditions for reasons I discuss below. However, it is my opinion that equating these historical conditions with natural conditions is not correct.

Anthropogenic modifications to the Delta and its watershed occurred following European settlement in the mid-18th century and accelerated following the California gold rush in the 1850s. Riparian vegetation was removed, wetlands were drained, and levees were constructed to reduce the natural annual cycle of flooding upstream of the Delta. These activities resulted in a system-wide trend towards lower evapotranspiration of valley floor precipitation and runoff that naturally drained to the Delta, likely resulting in Delta outflow that was higher than would have occurred under pre-gold rush conditions. During this period of the latter 19th and early 20th century prior to 1917, irrigated agriculture was in its infancy and was too small in scale to replace the water use associated with the natural landscape.

Climatic conditions in the latter 19th and early 20th century were much wetter than the subsequent period up to the present. Figure 18 shows a time series of decadal average runoff to the Delta watershed, as measured by the Eight River Index, for the period spanning WYs 1872 through 2015. Data plotted in this figure were obtained from the California Data Exchange Center and CCWD (2010) (Antioch-216). This figure clearly shows that the early part of the record, pre-dating WY 1921, is wetter than the latter part of

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the record. Thus, the prevailing climatic conditions suggest that this early historical period prior to 1917 was probably associated with fresh water conditions in the Delta.
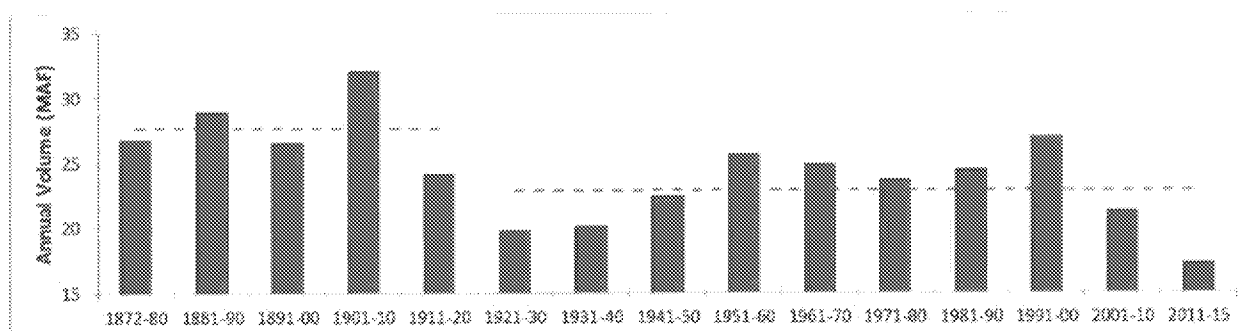
Figure 18. Annual average Eight River Index runoff volume by decade spanning Water Years 1872-2015. The early part of the record, pre-dating Water Year 1921, is wetter than the latter part of the record. The dashed line shows the annual period averages of 27.6 MAF for the pre-1921 period and 22.9 MAF for the post-1921 period.

An important data set that predates systematic monitoring of Delta salinity is based on records by the California Hawaiian Sugar Refining Corporation (C&H). Dr. Paulsen cites these data and a detailed analysis of these data in CCWD 2010 (Exhibit Antioch-216) to support her opinion. C&H, which obtained most of its fresh water supply in the early 20th century by transporting water to its refinery in Crockett, maintained a record on the distance its barges traveled up the San Joaquin and Sacramento Rivers to obtain fresh water. The period prior to 1917 when C&H collected barge travel data (1908-1916) was abnormally wet; 6 of the 9 years were classified as "wet" according to the 40-40-30 index. Thus, it is my opinion that these data do not provide a representative cross-section of this level of development, let alone represent natural conditions.

As part of my analysis, I compared the C&H barge travel data as reported in DPW (1931) (Exhibit Antioch-233), CCWD (2010) (Exhibit Antioch-216), and Means (1928) (Exhibit Antioch-232) and determined that the data presentation in Exhibit Antioch-216 was not consistent with the other exhibits. It is my opinion that the data presentation in Exhibit Antioch-216 is systematically biased (i.e. offset by a phase shift) due to a misinterpretation of the data graph presented in Exhibit Antioch-233. Specifically, the data presented in

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Exhibit Antioch-216 appear to be shifted forward in time by half a month, resulting in biased reporting related to timing of initial and peak seawater intrusion. It is my opinion that the Water Board should be cautious in its assessment of Dr. Paulsen's and the CCWD 2010 report's presentation of the C&H data.

IV.C. UNIMPAIRED FLOW IS NOT AN APPROPRIATE MEASURE OF NATURAL FLOW ON THE VALLEY FLOOR OR IN THE DELTA.

Based on my analysis, it is my opinion that unimpaired flow is not an appropriate measure of natural flow on the valley floor or in the Delta because, as described below, the theoretical unimpaired Delta outflow calculation as described in the 2010 Flow Criteria Report is systematically higher than the corresponding natural Delta outflow estimate.

Conceptually, the unimpaired Delta outflow calculation assumes the same rim inflows and valley floor precipitation used in the natural Delta outflow estimate discussed previously. However, rather than reducing water supply to account for water use associated with the full extent of natural vegetation on the valley floor, the unimpaired outflow calculation assumes that water use upstream of the Delta is limited to only valley floor precipitation. Thus, the unimpaired outflow calculation effectively assumes rim inflows pass through the valley floor and arrive in the Delta in the current system of channel improvements, levees, and flood bypasses. Thus, by definition, unimpaired Delta outflow calculations provide a high estimate when used as a surrogate for natural Delta outflow. Figure 19 compares annual average unimpaired and natural Delta outflow estimates by water year type as well as full period average spanning WYs 1922 through 2014. Under average conditions, the annual unimpaired flow is 43 percent higher than the natural flow estimate. This finding is in stark contrast to the Phase II Scientific Basis Report (p. 5-6) which states that, while unimpaired flow is not the same as natural flow, it is generally reflective of the magnitude of the natural flows to which fish and wildlife have adapted.
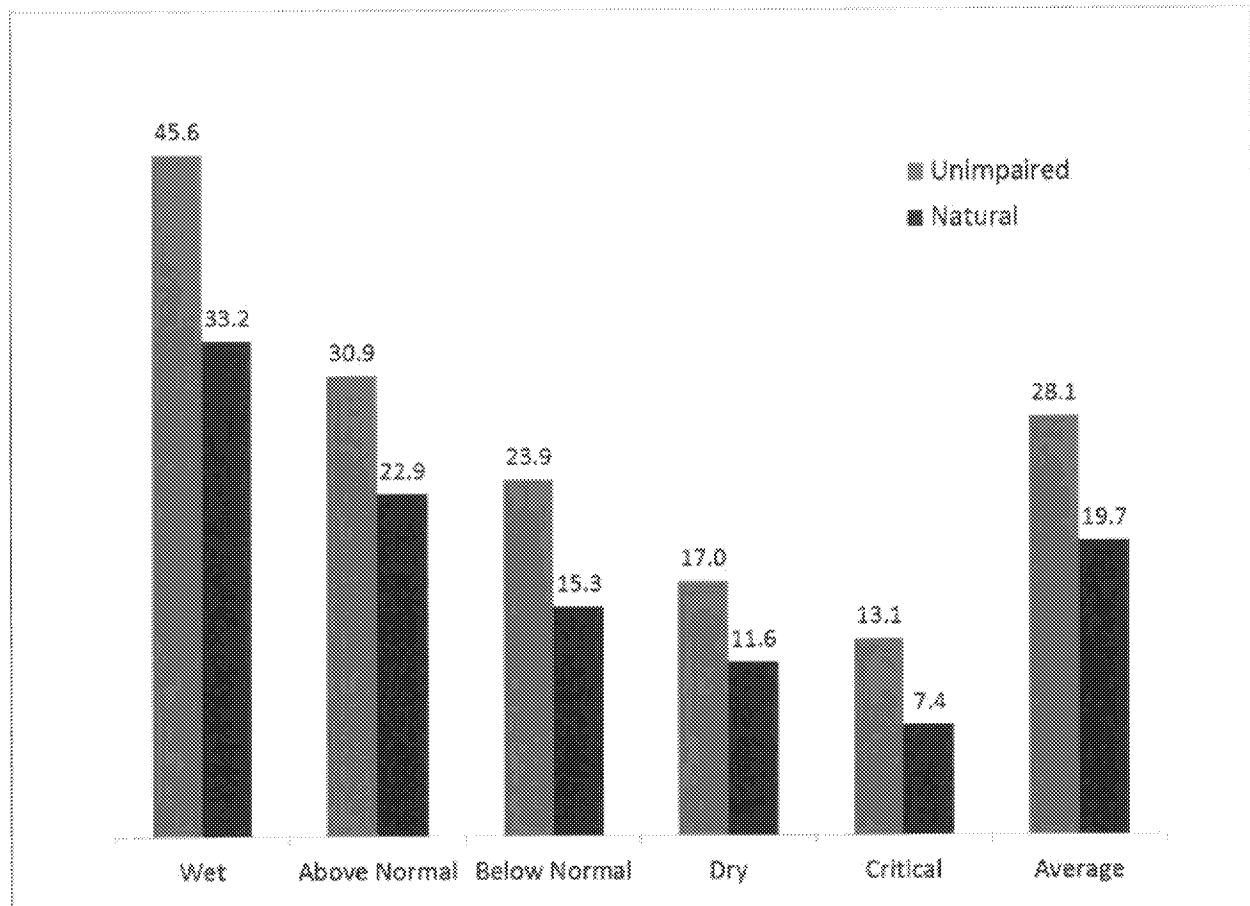
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Figure 19. This chart compares annual average "unimpaired" and "natural" Delta outflow estimates (in units of million acre-feet) for the 93-year hydrologic period spanning WYs 1922 through 2014. Comparisons are shown by 40-30-30 WY type as well as the full period average. This chart clearly shows that unimpaired flow estimates are significantly higher than natural flow estimates under all hydrologic conditions. Under average conditions, the annual unimpaired flow estimate is 43 percent higher than the natural flow estimate. (From Exhibit DWR-1384.)

IV.D. NATURAL CONDITIONS CANNOT BE RESTORED USING THE UNIMPAIRED FLOW HYDROGRAPH

It is my opinion that the use of unimpaired flow calculations to regulate Delta flows, as proposed in the 2010 Flow Criteria Report, will not restore natural conditions in the Delta and its watershed. In the highly altered contemporary system, a flow regime based on unimpaired flow would not provide natural flow functions, as it would merely provide for transport functions (i.e., increasing water depth and velocity) in leveed and rip rapped channels. As the water contractors and others explained during the 2012 Water Board workshops (Exhibit DWR-1333), the literature relevant to using unimpaired flows as a restoration tool cautions that the outcome, particularly in highly altered systems, is highly

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uncertain. (See Exhibit DWR-1333 pp. 6-2 to 6-5, citing Poff et al. (1997) (Exhibit DWR-1332), Poff and Zimmerman (2010) (Exhibit DWR-1330), Pierson et al (2002) (Exhibit DWR-1331), and Bunn and Arthington (2002) (Exhibit DWR-1382) ["The advice from aquatic ecologists on environmental flows might be regarded at this point in time as largely untested hypotheses about the flows that aquatic organisms need and how rivers function in relation to flow regime."].

Historically, the water and landscape were much more interconnected. High flows would spill out onto the landscape, creating spawning and rearing habitat and feeding the rivers as it slowly drained back into the main channels. These return flows would carry nutrients, detritus, and lower trophic organisms produced in these nutrient rich, often shallow and slow-moving waters. Merely putting more water down rip-rap lined levees does not recreate these historical conditions.

V.   CONCLUDING OBSERVATIONS

The focus on ecological restoration frames the challenges of managing today's Delta squarely in terms of comparisons to historical conditions. The testimony provided here provides much-needed context for ongoing ecosystem management efforts in the Delta, particularly efforts that seek to relate Delta outflow and X2 to various ecological metrics. A key challenge associated with interpreting results from ecosystem-oriented data analyses is the absence of biological data for the Delta prior to the 1960s. Thus, biological inferences are based on a truncated subset of the flow and salinity record which, as my testimony has shown, are not representative of the trends associated with the full period of observed data. Importantly, even the full hydrologic record is not indicative of pristine or natural conditions, because land use development prior to the 1920s had already led to well-documented alterations in flow and salinity.

Executed on this 1st day of July, 2018 in Sacramento, California.

Paul Hutton

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